AIAA-2017-0287

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NASA AMS Seminar

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U.S. ARMY RDECOM

New Capabilities in Version 7 of the CREATE™-AV Helios Rotorcraft Simulation Code

AMRDEC

Approved for public release; distribution unlimited.
Review completed by the AMRDEC Public Affairs Office (PR2696, 12 Dec 2016)

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

B. Jayaraman, *STC Corp, NASA Ames*
J. Sitaraman, Parallel Geom Algs LLC
B. Roget, *STC Corp, NASA Ames*
V. Lakshminarayan, *STC Corp, NASA Ames*
J. Leffell, *US Army ADD*
J. Forsythe, *NAVAIR*

Presented by:

Andrew Wissink

Aerospace Engineer
Aviation Development Directorate

Aviation and Missile Research, Development and Engineering Center

Moffett Field, CA

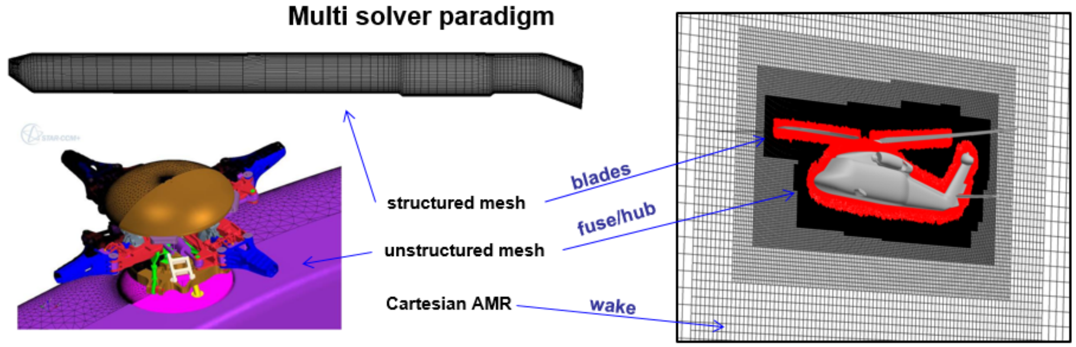
Presentation Outline

- **Helios v7 new capabilities**
  - mStrand meshing and solver
  - FUN3D and kCFD support
  - New GUI
  - Tight Coupling Maneuver
- **Validations**
  - Rigid rotor in hover - TRAM
  - Elastic rotor in forward flight – UH-60A
- **Concluding Remarks**

Helios High-Fidelity Rotorcraft Analysis Tool

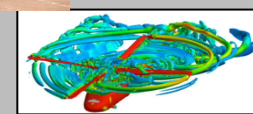
- **Helios is the Rotary-wing product of the DoD CREATE™ Air Vehicles program**
  - **Multi-mesh/multi-solver paradigm**
    - Strand, Unstructured or Structured near-body
    - High order Cartesian off-body
    - Adaptive Mesh Refinement
    - Fast overset connectivity

Multi solver paradigm

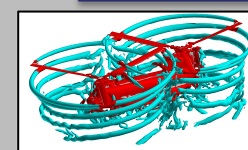


  - **Interfaces to RCAS for structural dynamics and trim**
- **Runs on distributed memory high performance parallel computer systems**

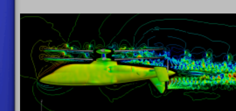
Version 7



Capabilities
- CFD/CSD coupling
- Full vehicle – rotors & fuselage
- Multiple rotors
- Free flight trim



Key Technologies
- Multi-mesh paradigm
- Adaptive mesh refinement
- High order Cartesian solver
- Python-based common software infrastructure
- Generalized interface to comprehensive codes



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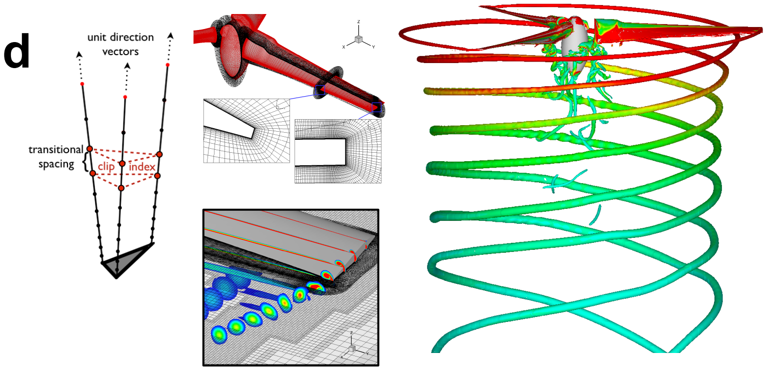
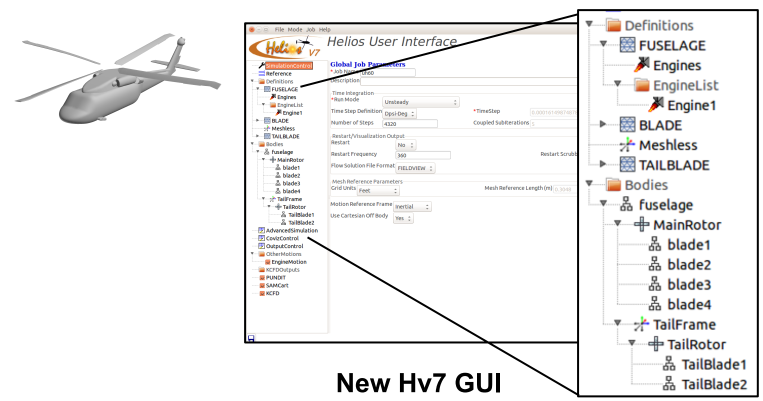
Helios v7 – New Capabilities

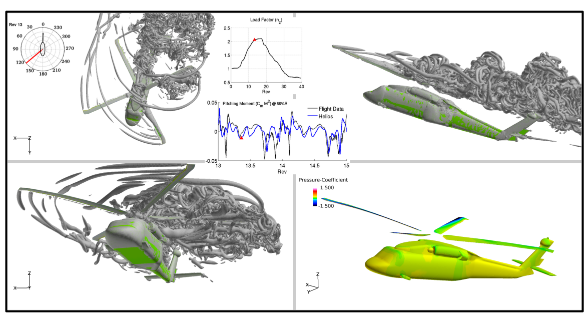
- **Near-body Strand mesh generation and solver - *mStrand***
  - Automated grid generation
  - Efficiency flow solution
- **Two new unstructured solvers**
  - *FUN3D* unstructured solver from NASA
  - *kCFD* unstructured solver from CREATE^{TM}-AV Kestrel team
- **Tight coupling maneuver**
- **Redesigned GUI**
  - Body hierarchy setup
  - Motion specification



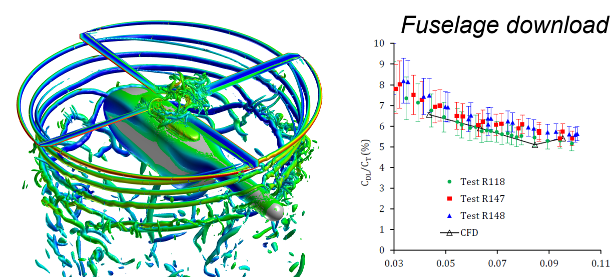
***mStrand* solutions – Lakshminarayan**



New Hv7 GUI



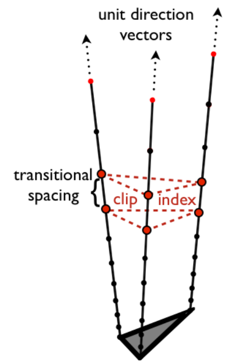
UH-60 maneuver – Roget, Sitaraman



***Transition modeling with FUN3D* & *OVERFLOW* – Jain**

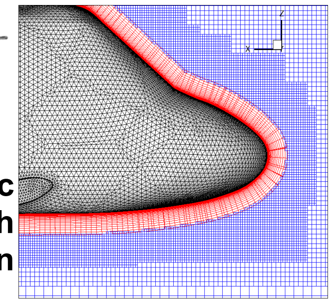
Strand Meshing & Solver

- <u>**Automated**</u> **near-body mesh generation**
  – Multi-strand generation from CAD
    R. Haimes. B. Roget, J. Sitaraman
- **Requirements to make strand meshing work**
  – Adaptive Cartesian off-body (2010)
  – Scalable efficient domain connectivity (2012)
  – Multi-strand mesh gen around convex corners (2014)
  – Strand-specific flow solver (2016)
  – Self-intersecting strands for concave corners (2017)
- **Hv7 is the first production code with automated strand capability**

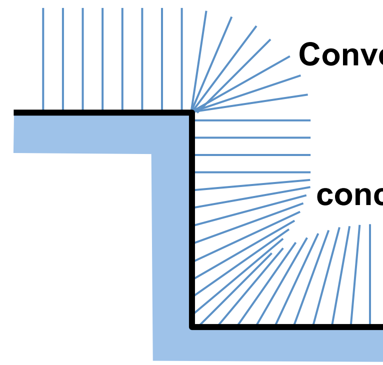


Strands

Complex geometries

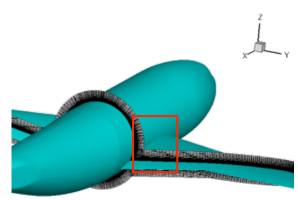


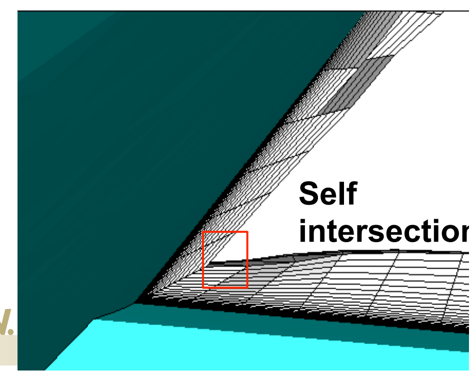
Automatic volume mesh generation



Convex - multi-strand

concave





Strand Mesh Generation

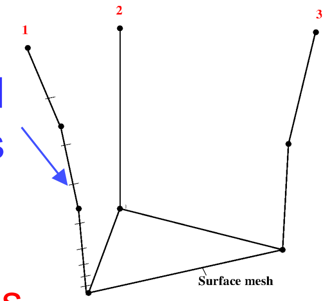
AMRDEC

- **Scripted mesh generation**
  - Generates multi-strand mesh a short distance from the surface using MOSS-based scheme
  - Constructs layers of <u>sub-divided</u> strands out to specified strand length
- **Tested and validated for rotor blades**
  - TRAM, UH60, S-76

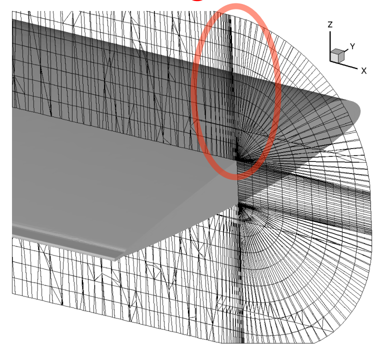
1. Surface mesh in *.vtk format
2. Specify parameters to script:
   - # strand layers (60)
   - Strand length (1.0)
   - Spacing at wall and extent (4.e-5, 0.05)
   - Surface grid file (surf.vtk)

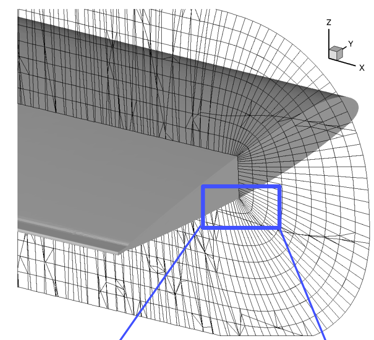
```
HELIOS/bin/makeStrandMesh -n 60 -o 1.0 -d 4.0e-5 .05 surf.vtk
```

Sub-divided (bent) strands

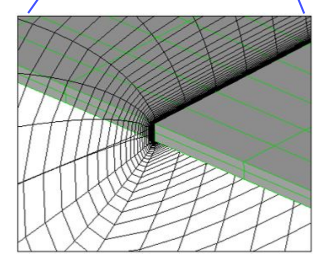


Straight strands

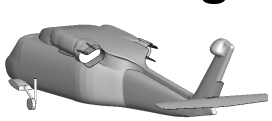


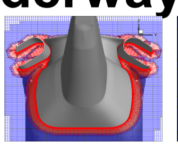


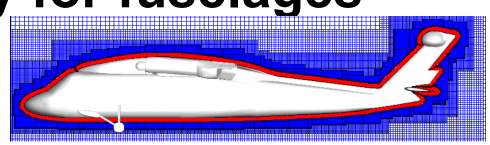
bent



- **Testing underway for fuselages**

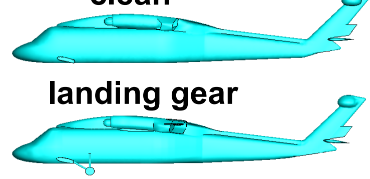


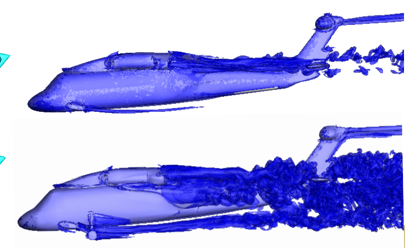




clean

landing gear

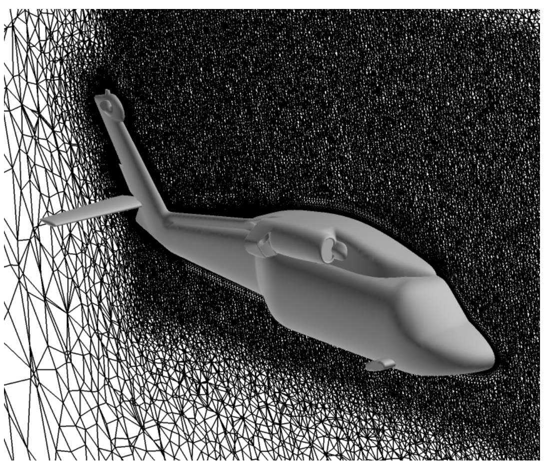




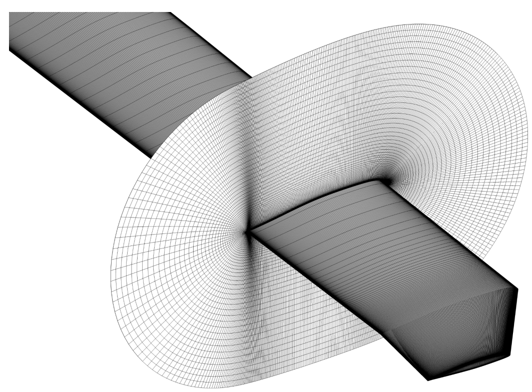
Overset Multi-Solver Paradigm

- **Complexities in modeling rotorcraft aerodynamics**
  - Complex geometry
  - Accurate prediction of transonic flow and vortex formation on blades
  - Transition and separated flow – e.g. hub, rotor stall
  - Interactional effects

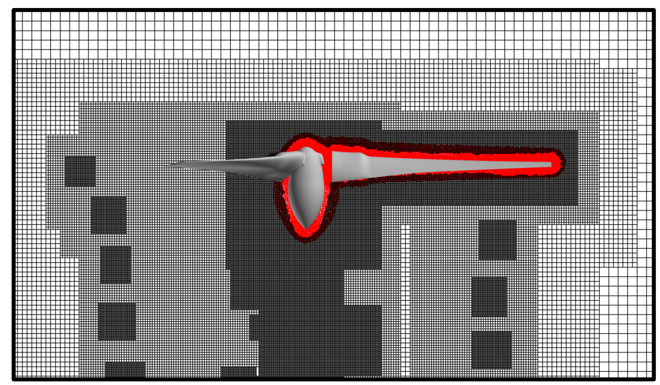
Multi-solver approach seeks to apply optimal solver to the different flow regimes modeled



Geometrically Complex Fuselage/Hub
Strand or **Unstructured**



Geometrically Simple Rotor Blade
Strand or **Structured**



Wake and Interactional Aerodynamics
High Order Cartesian AMR

Hv7 Near-body Solvers

- **Support for strand, unstructured, and structured near-body solvers**

CREATE

mStrand - strand
kCFD – unstructured

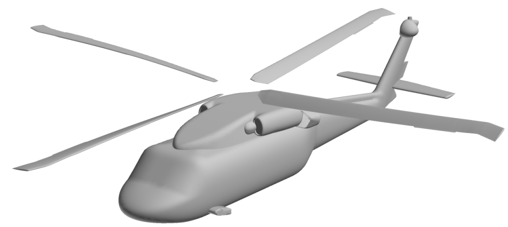
NASA
FUN3D - unstructured
OVERFLOW – structured

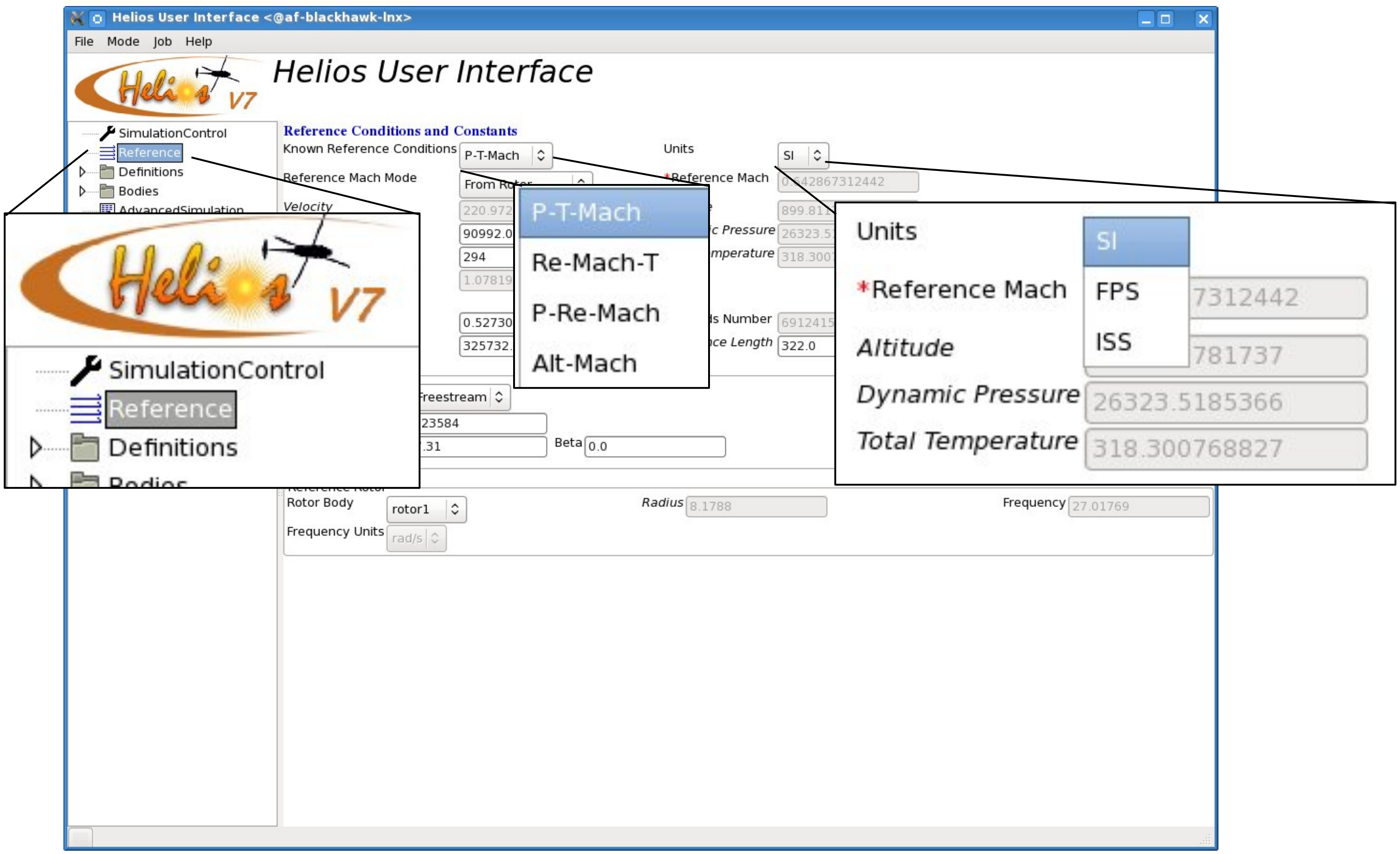
U. Wyoming
NSU3D – unstructured

- **All solvers adhere to common near-body solver API in Helios Python-based infrastructure**
- **External solver interfaces developed through collaboration between R. Jain of US Army and code developers at NASA**
  - *FUN3D 13.0* – R. Biedron, B. Lee-Rausch
  - *OVERFLOW 2.2m* **–** P. Buning
- **Availability of multiple solvers useful to the practicing engineer**
  - Known algorithms, validated datasets
  - Different turbulence model implementations and parameters

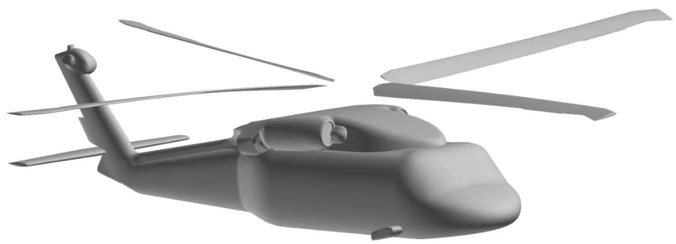
Redesigned GUI

- **Flexible reference condition specification**
  - Pressure, Temp, Mach, Altitude, Re, etc.
  - SI, FPS, ISS unit systems supported

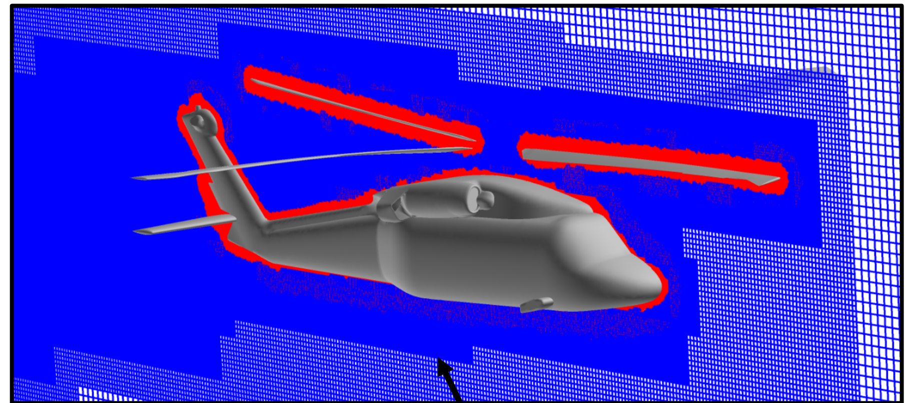




Multi-Solver Selection

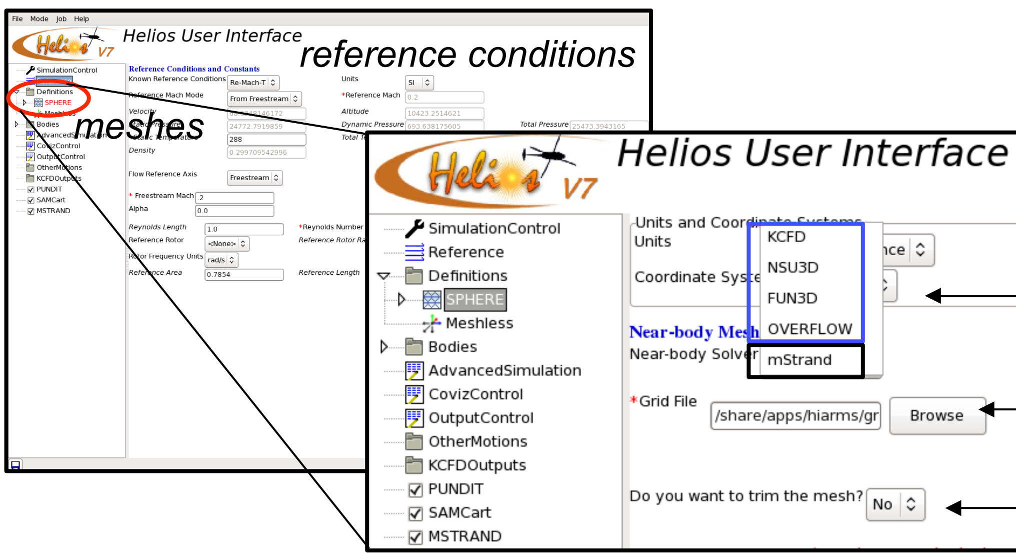


Preferred near-body solver selected in GUI with mesh type



Automatically generated off-body Cartesian AMR mesh

Helios GUI



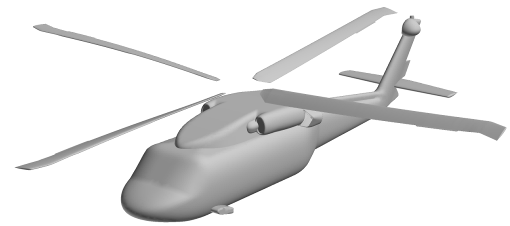
Near-body solver choices

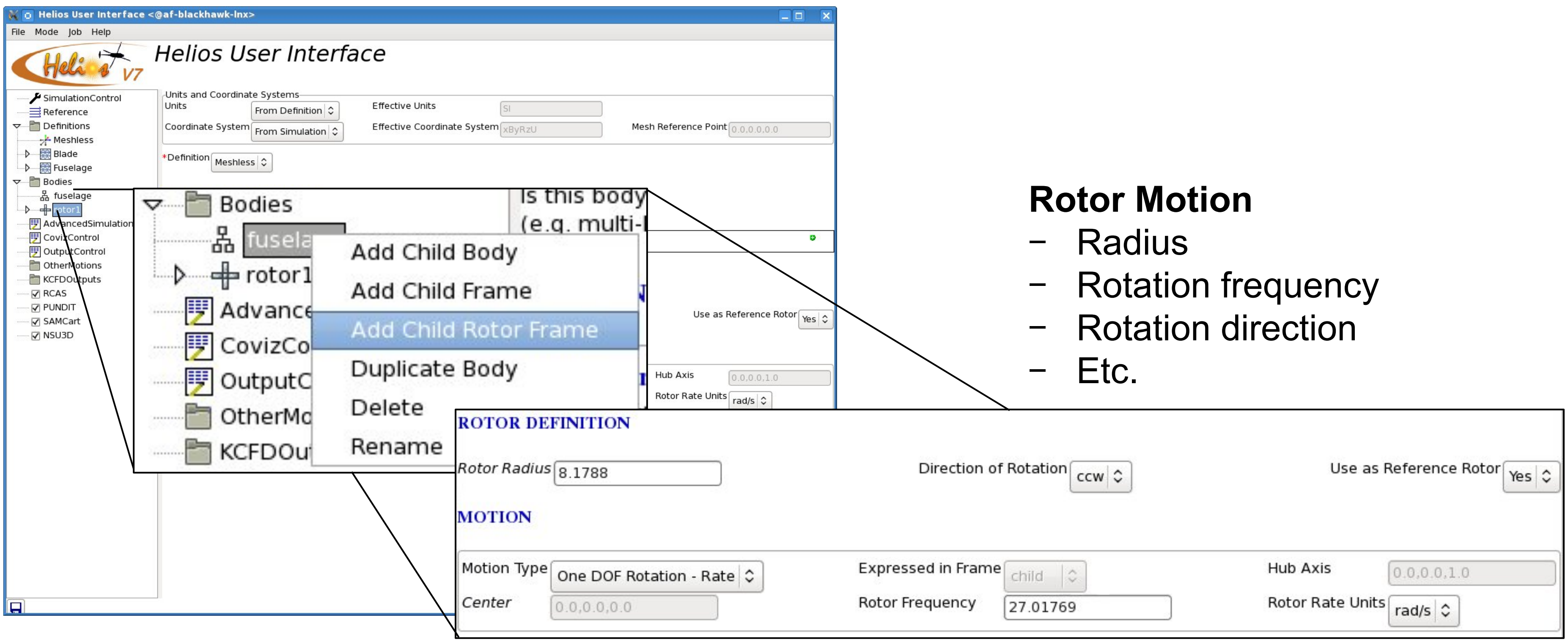
mesh

Trim distance

Bodies/Frames

- **Can define hierarchy of frames and bodies**
  1. Moving “rotor” frame as child of fuselage
  2. “blade” bodies linked to frame
- **Useful for setting up complex multi-component vehicles**



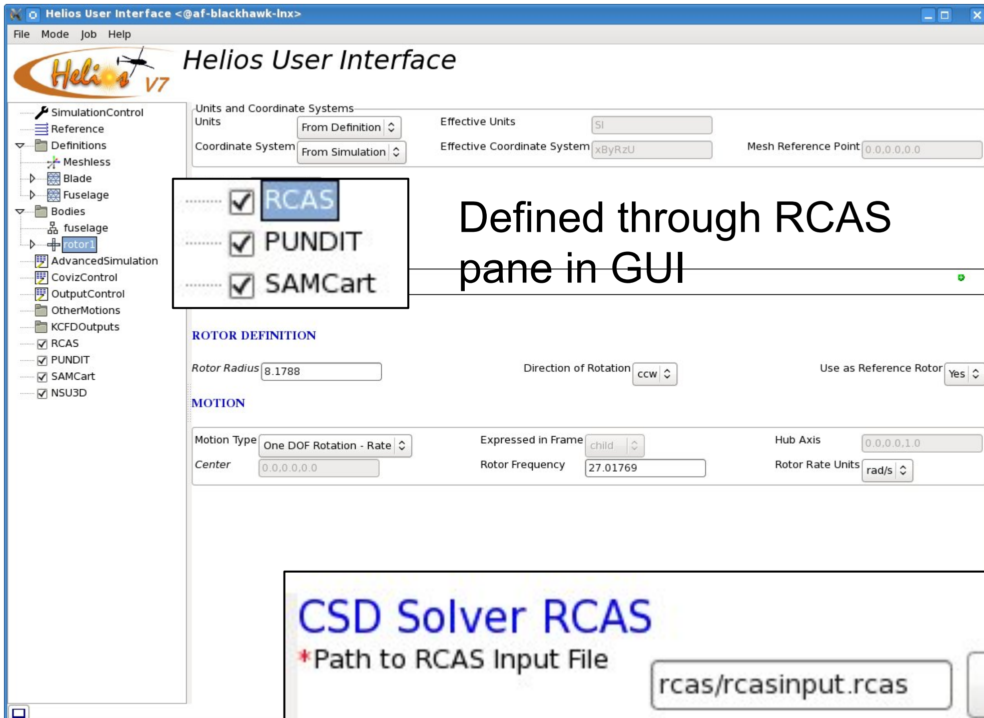


Rotor Motion

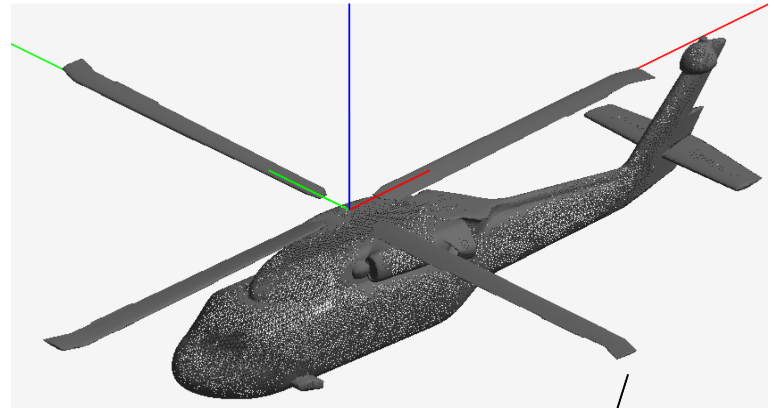
- Radius
- Rotation frequency
- Rotation direction
- Etc.

Tight Coupling Maneuver

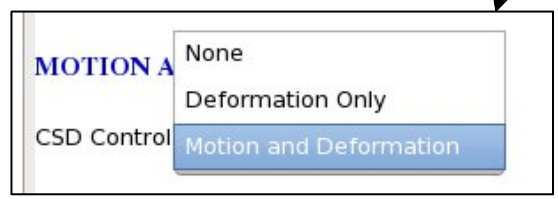
- **Tight coupling maneuver supported**

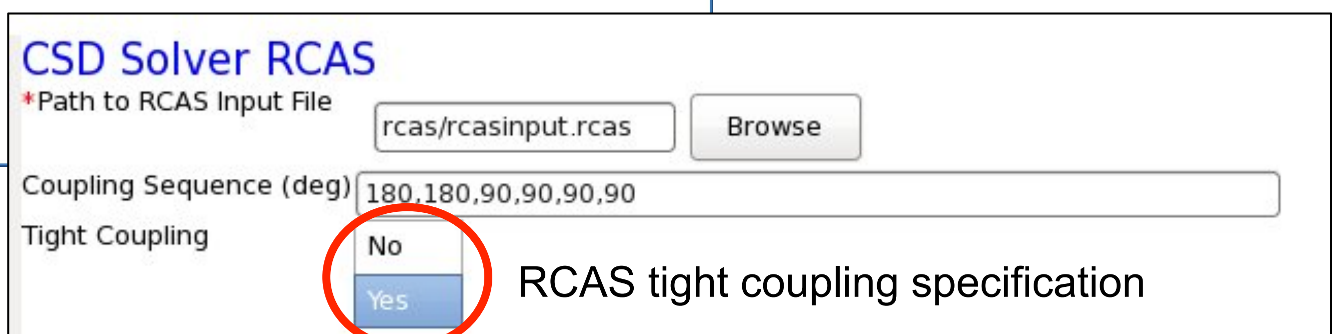


Defined through RCAS pane in GUI



Motion and deformation from RCAS

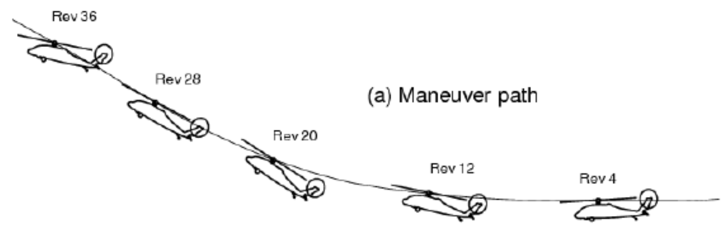


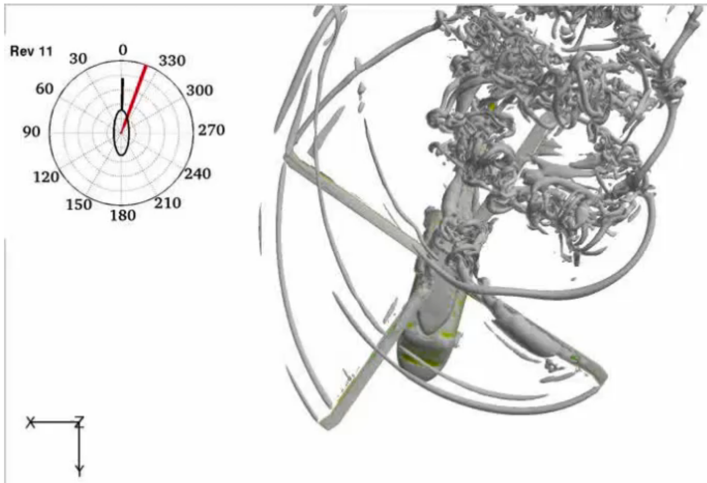


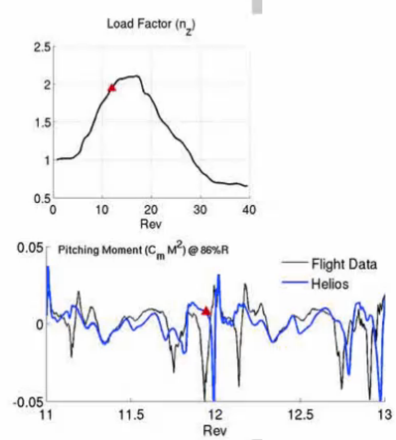
RCAS tight coupling specification

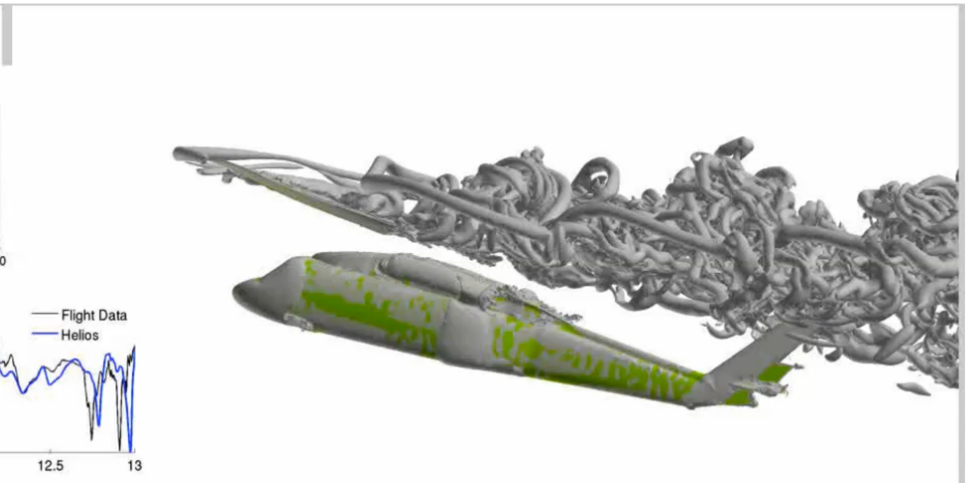
Maneuver

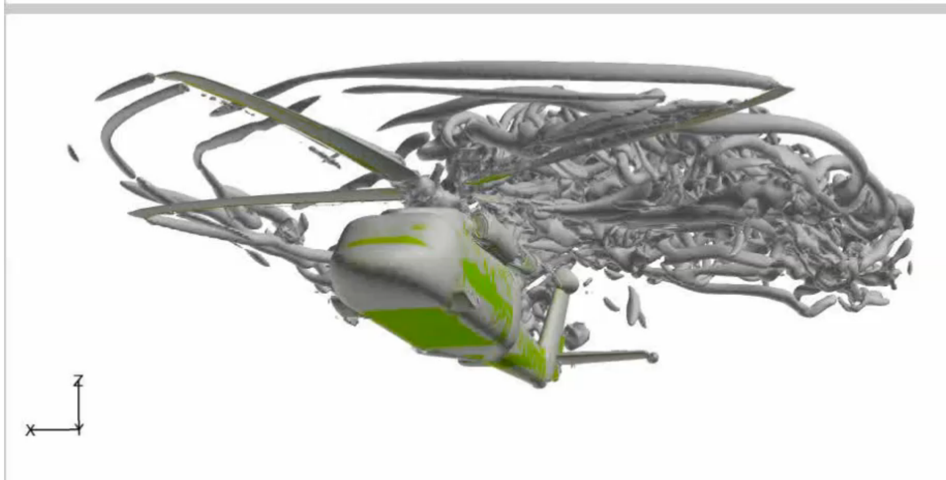
- **UH-60A C11029 UTTAS Pull-Up maneuver**
  - 40 revs, 9 sec (real-time)
  - Flight path angle 3 deg at start to 35 deg at end

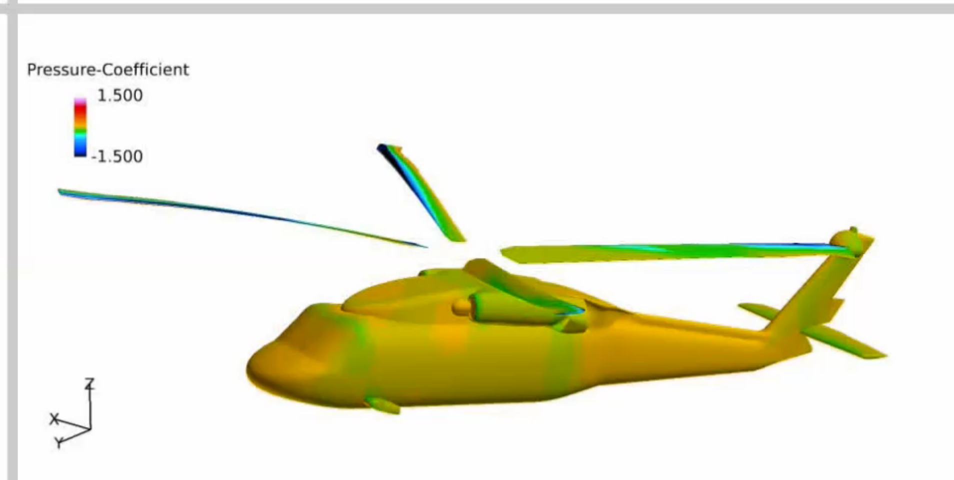












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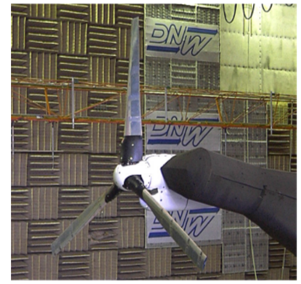
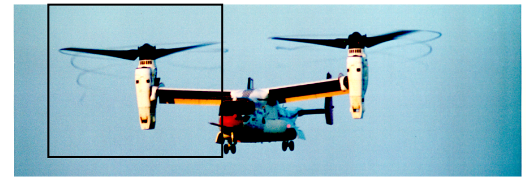
TRAM Rotor

- **Tilt Rotor Aeroacoustics Model (TRAM)**
  - Quarter-scale model V-22 Osprey
  - Tested in DNW-LLF facility
  - Definitive dataset for CFD validation



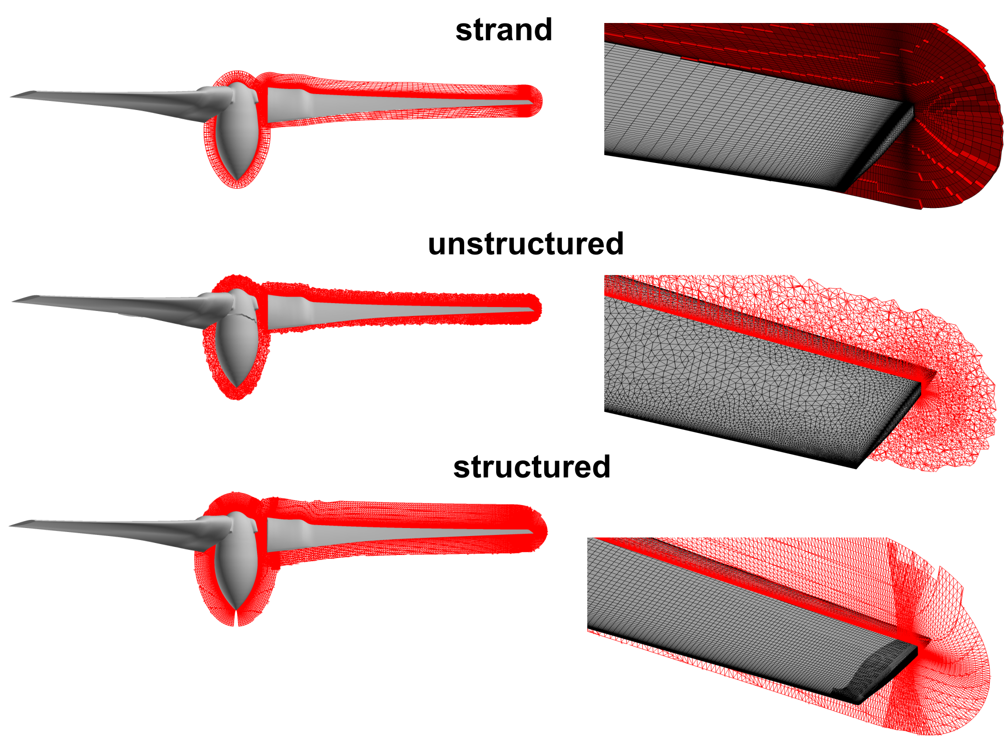
0.25-scale TRAM



V-22 Osprey

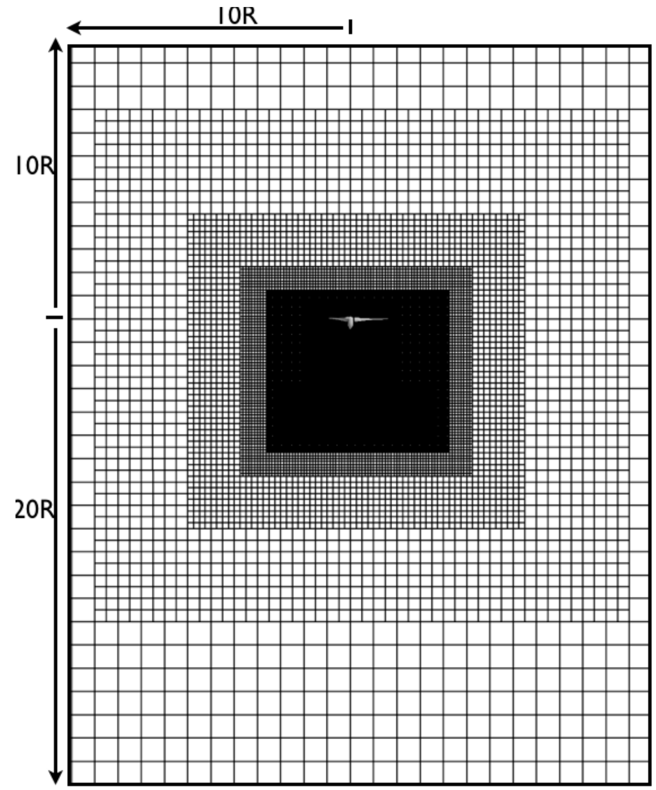
- **Computational conditions**
  - Isolated hover, 14 deg coll
  - Rigid blade
  - 8 revs, 0.25 deg/timestep
  - SA-DES w rot correction
  - M_{tip}=0.625, Re_{Tip}=2.1M

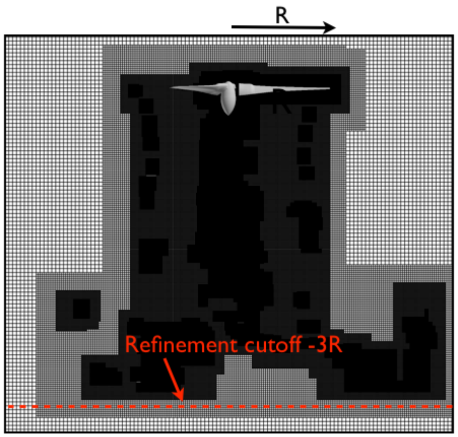
Gridpoints	Near-body blade	Near-body total	Off-body
Strand mstrand	2.1M	6.7M	287.2M
Unstructured kcfd,fun3d,nsu3d	3.1M	8.0M	270.6M
Structured overflow	3.7M	13.0M	261.1M

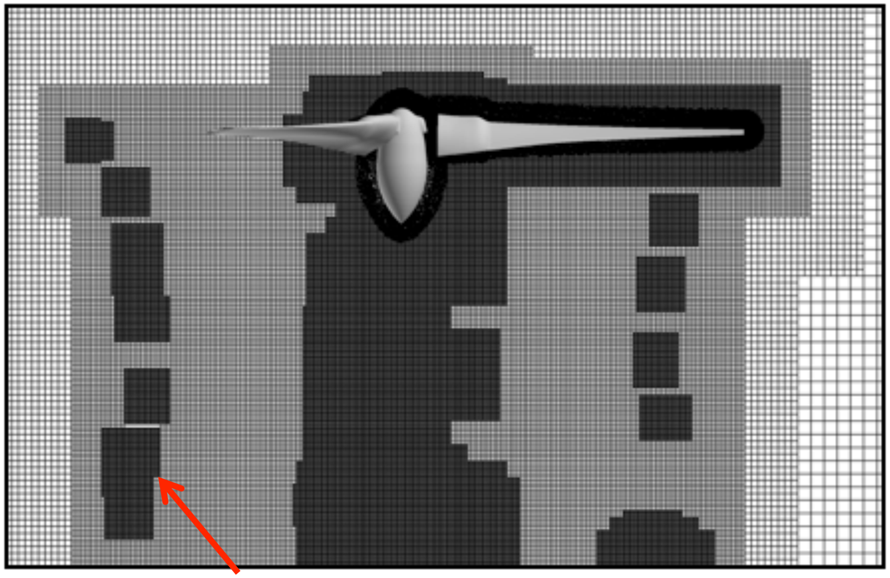


TRAM Rotor
Wake Mesh

- **Adaptive off-body mesh**
  - Geometry and solution refinement applied
  - 8 Levels
  - Finest Δx = 0.05 chord

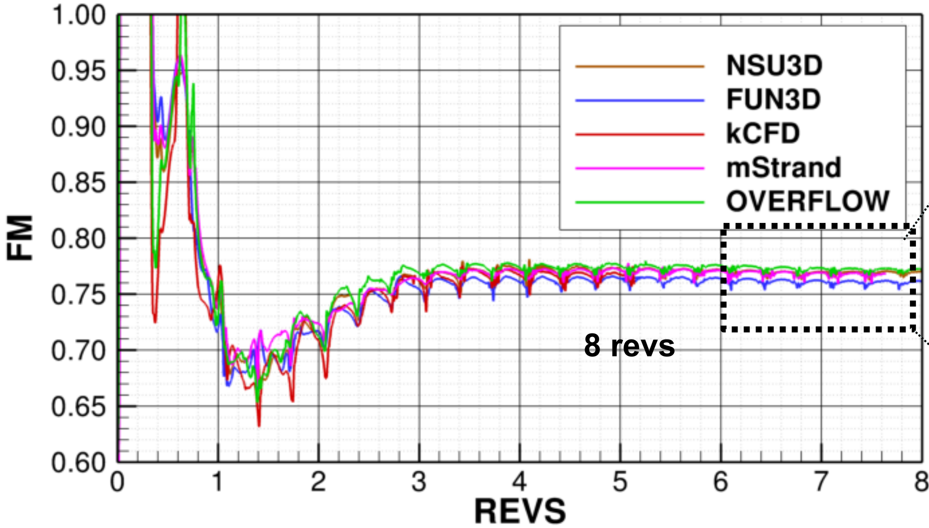


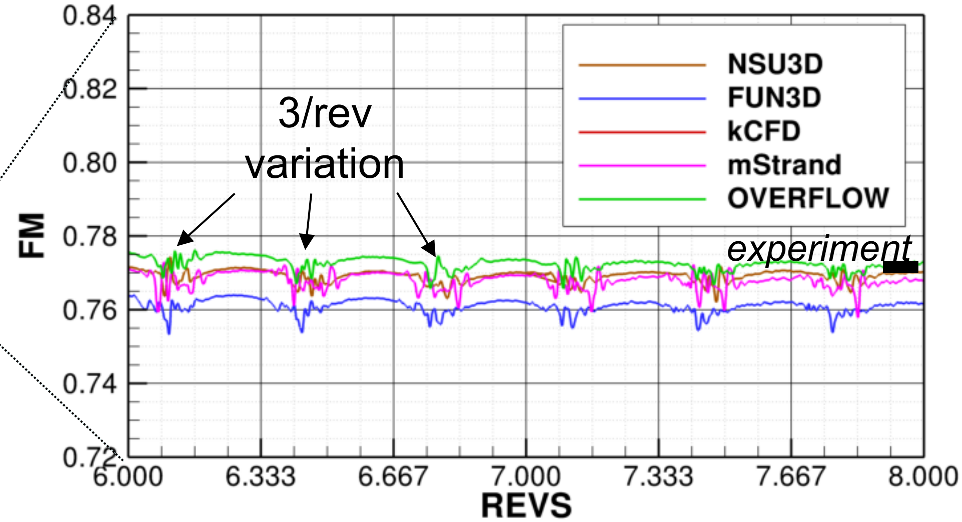




AMR targets local regions with swirling flow

TRAM Loads

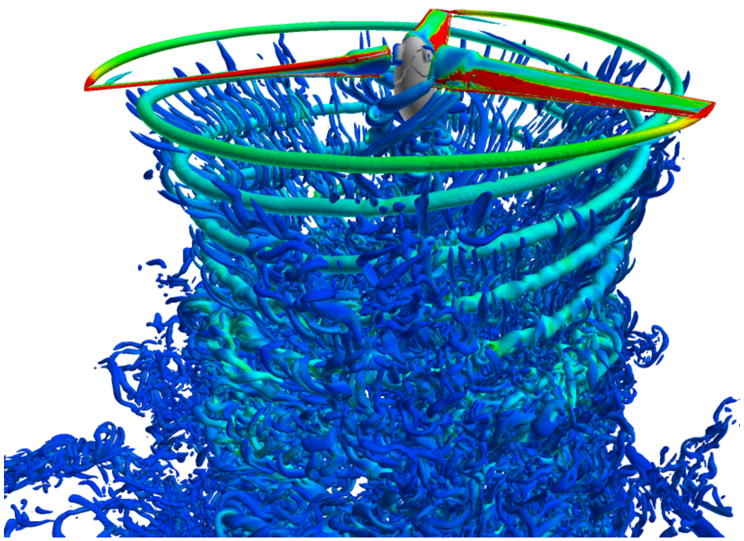




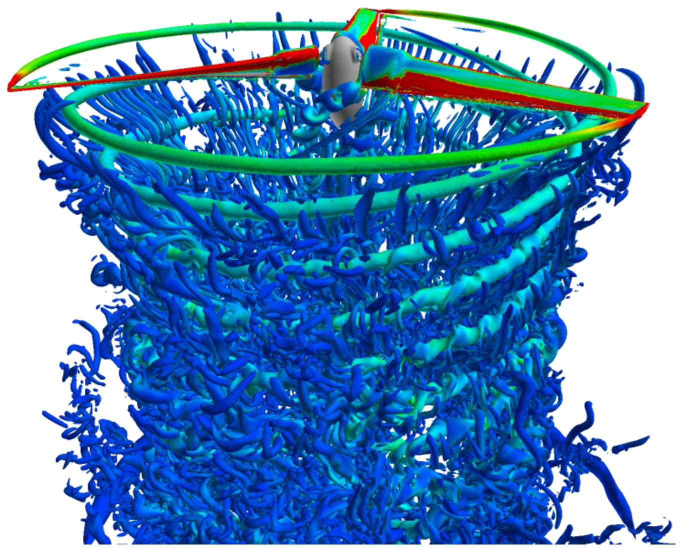
8 revs - forces avgd over last 2 revs	Thrust C_T/σ	Power C_Q/σ	Figure of Merit	% Diff from Experiment
Experiment	*0.1495*	*0.01596*	***0.774***	--
NSU3D	0.1453	0.01650	**0.769**	**-0.6%**
FUN3D	0.1448	0.01642	**0.761**	**-1.6%**
kCFD	0.1448	0.01648	**0.767**	**-0.9%**
mStrand	0.1435	0.01621	**0.769**	**-0.6%**
OVERFLOW	0.1445	0.01631	**0.772**	**-0.3%**

TRAM Wake

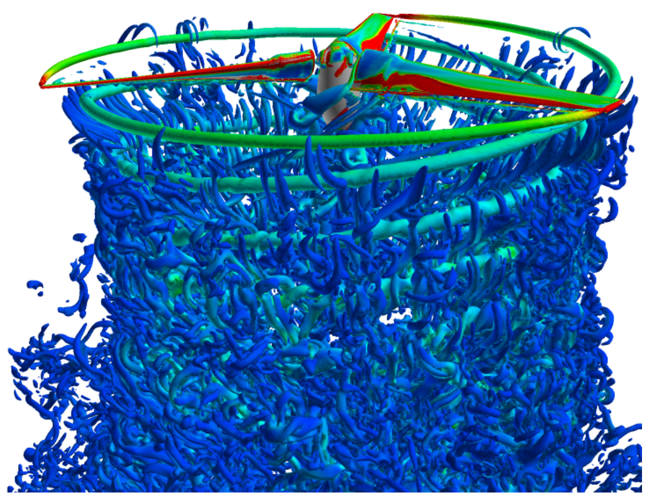
NSU3D



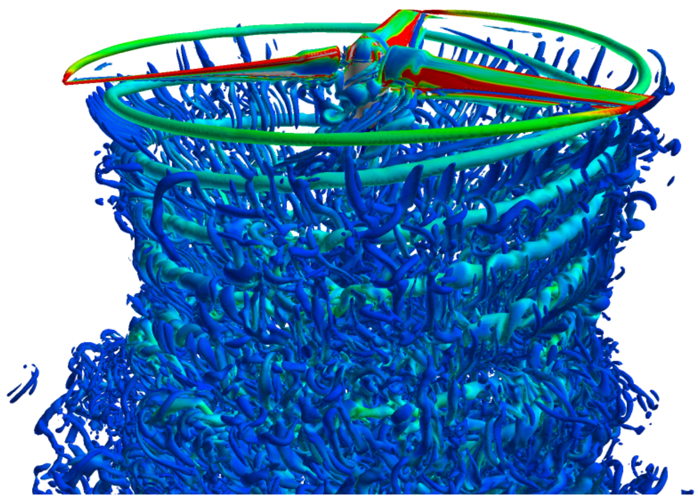
FUN3D



mStrand



OVERFLOW

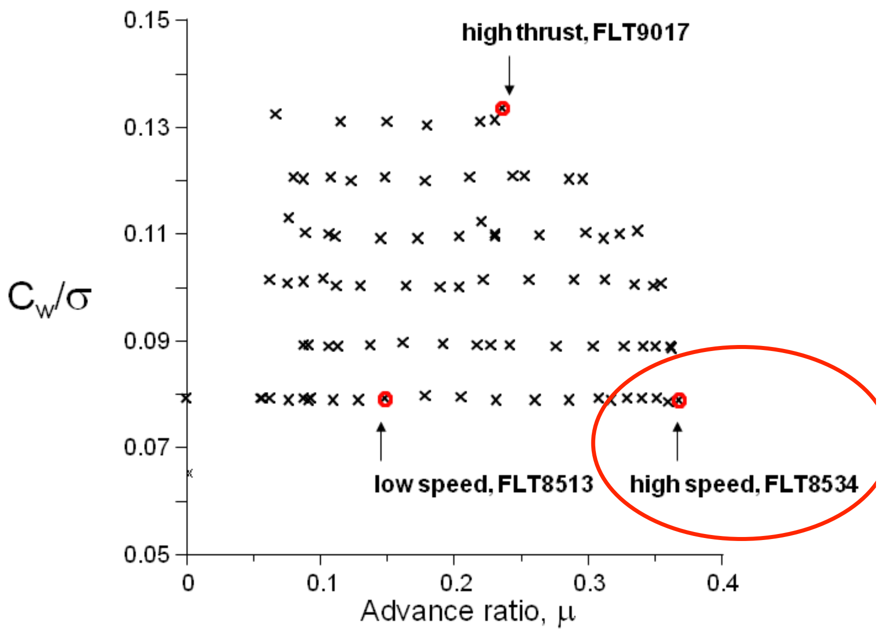


UH-60A rotor

- **UH-60A high speed flight**
  - 8534 condition
  - High vibratory loads
  - Transonic on advancing side
- **Isolated rotor (no fuselage)**
- **2 revs, CFD-CA coupling**

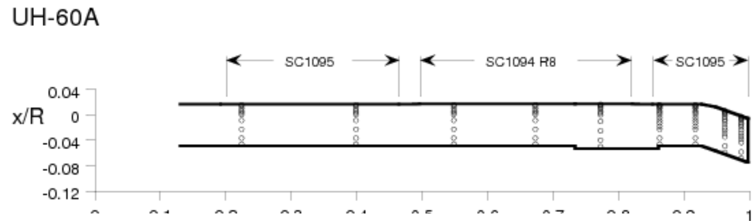
NASA/Army UH-60A airloads test

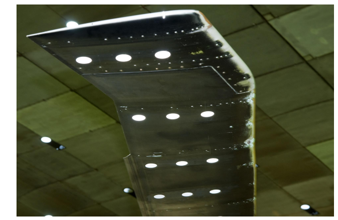
Gridpoints	**Near-body blade**	**Near-body total**	**Off-body**
Strand mstrand	3.73M	14.9M	89M
Unstructured kcfd,fun3d,nsu3d	4.14M	16.6M	107M
Structured overflow	4.48M	18.3M	105M

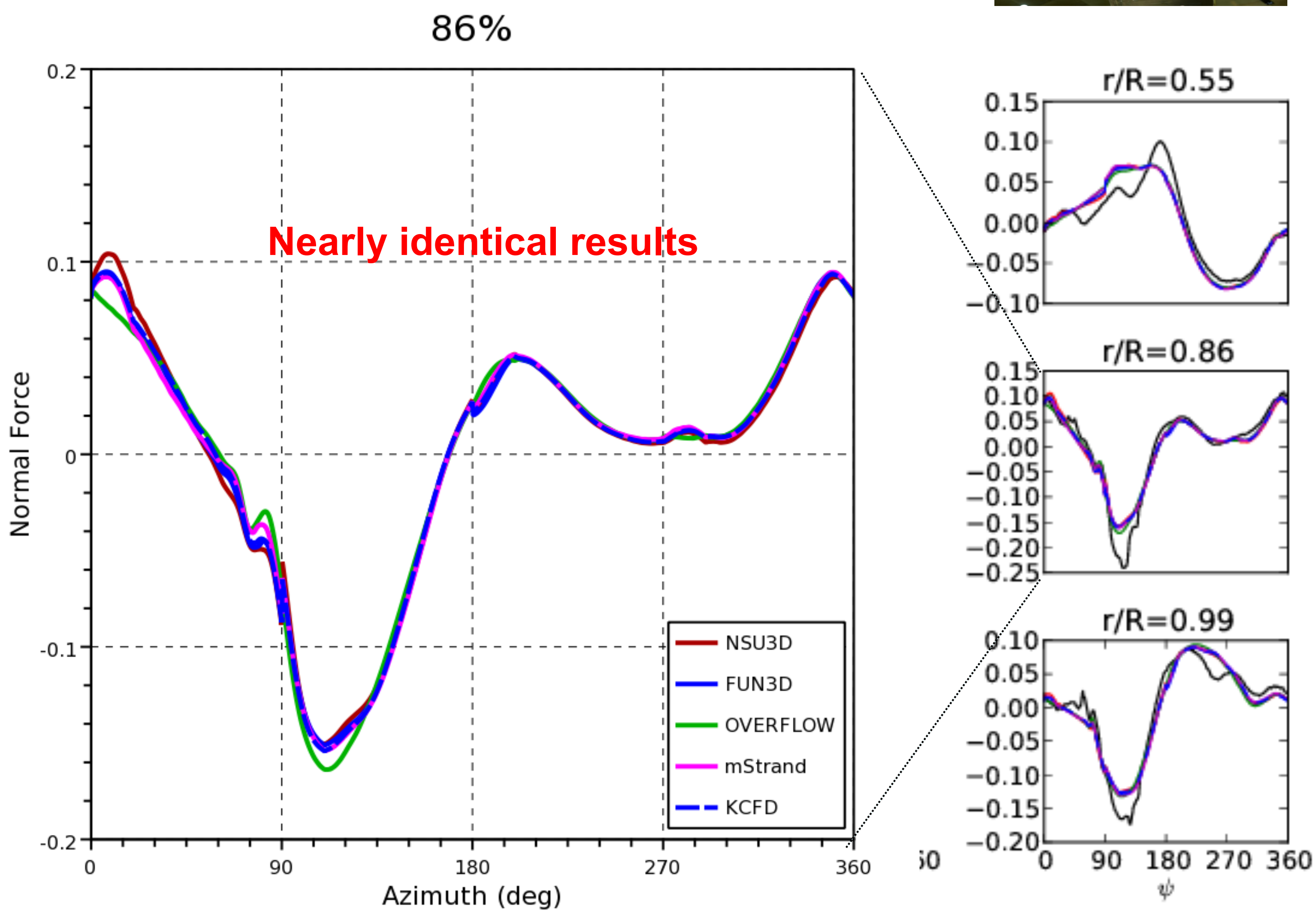


UH-60A Normal Force

- **Tested all near-body solvers available**
  - kCFD
  - NSU3D
  - FUN3D
  - mStrand
  - OVERFLOW

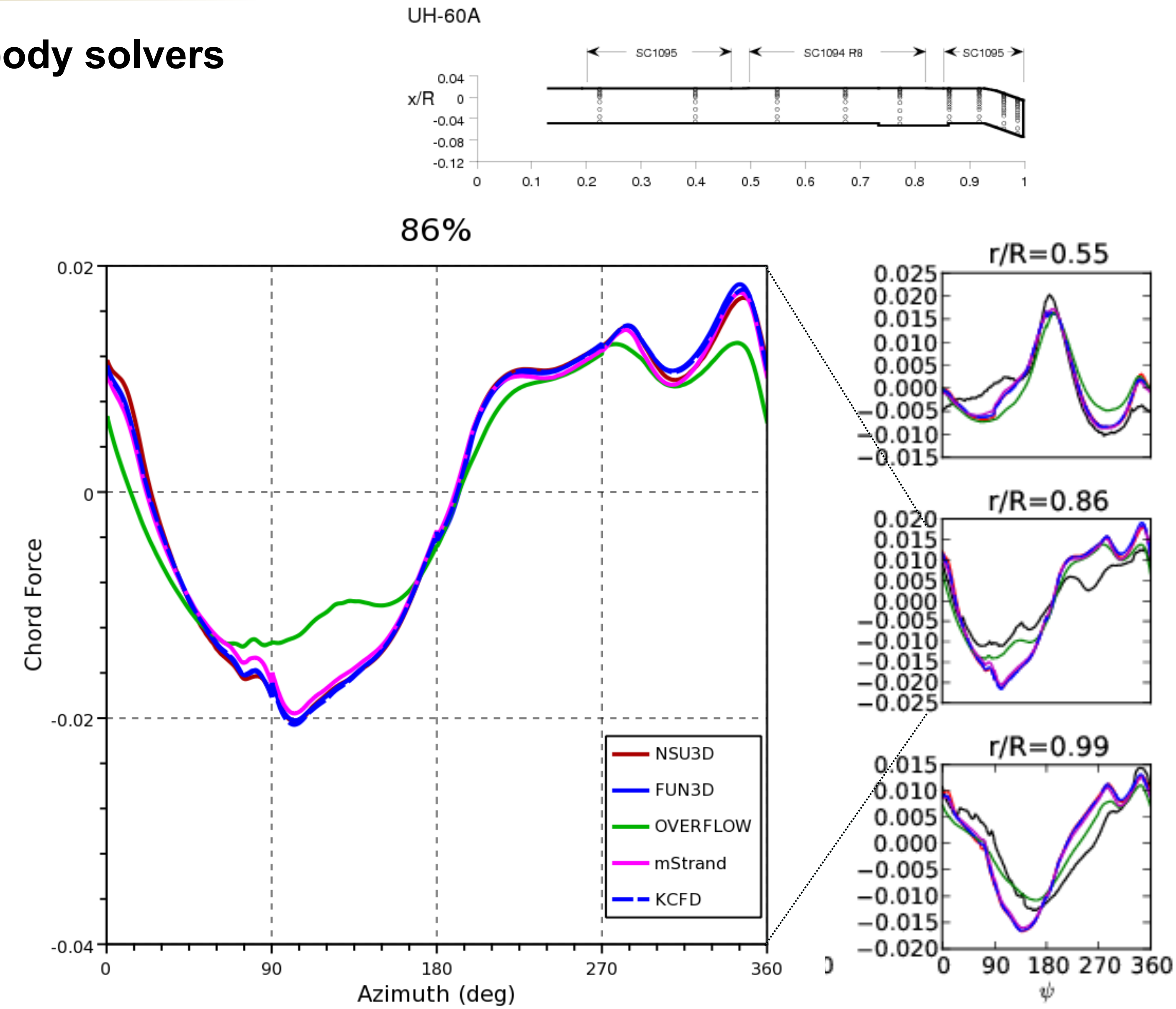






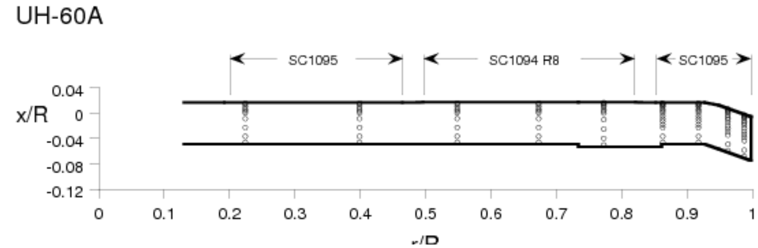
UH-60A Chord Force

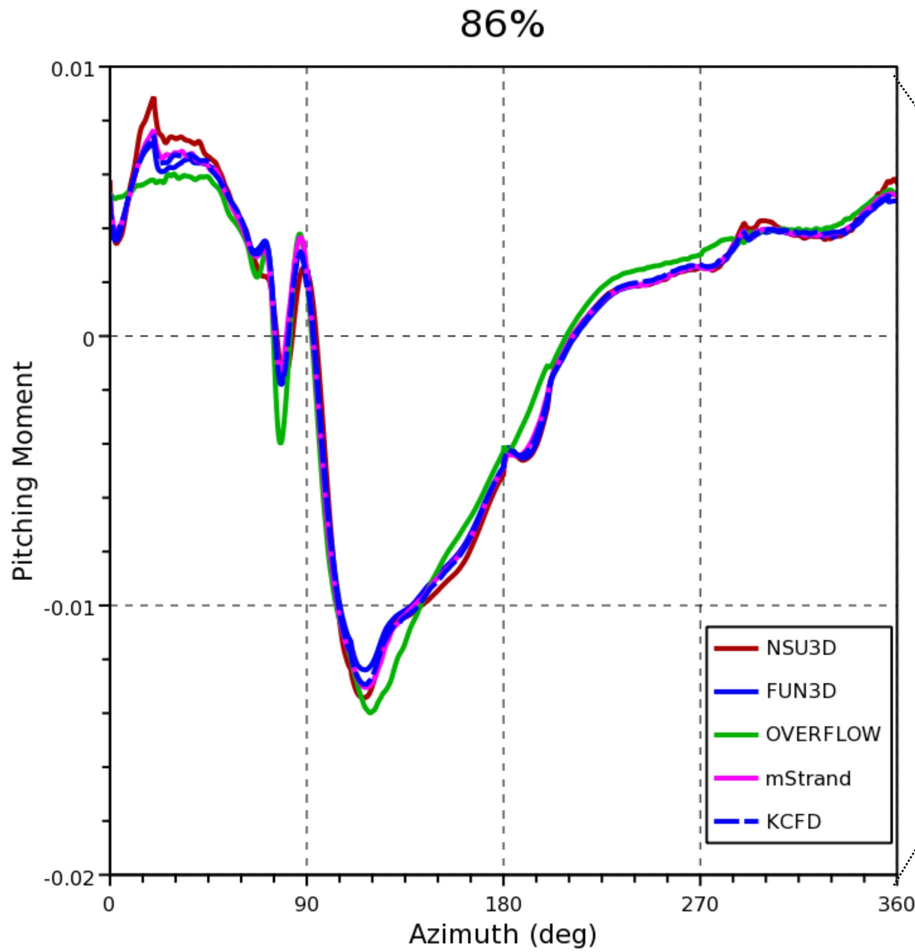
- **Tested all near-body solvers available**
  - kCFD
  - NSU3D
  - FUN3D
  - mStrand
  - OVERFLOW

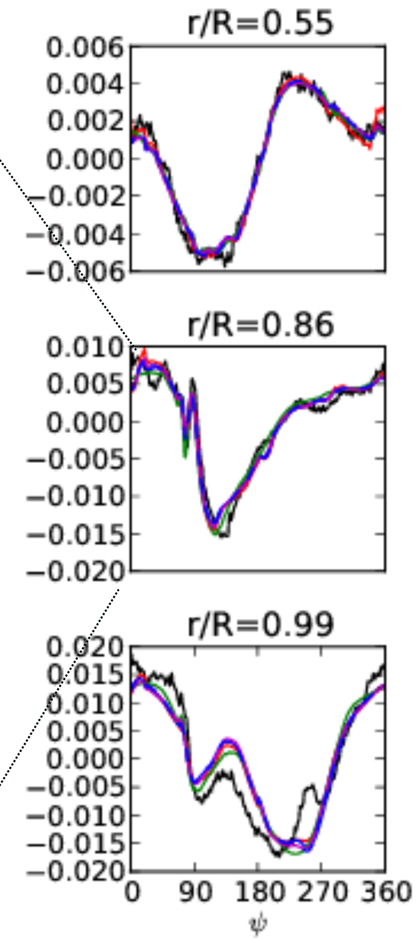


UH-60A Pitching Moment

- **Tested all near-body solvers available**
  - kCFD
  - NSU3D
  - FUN3D
  - mStrand
  - OVERFLOW

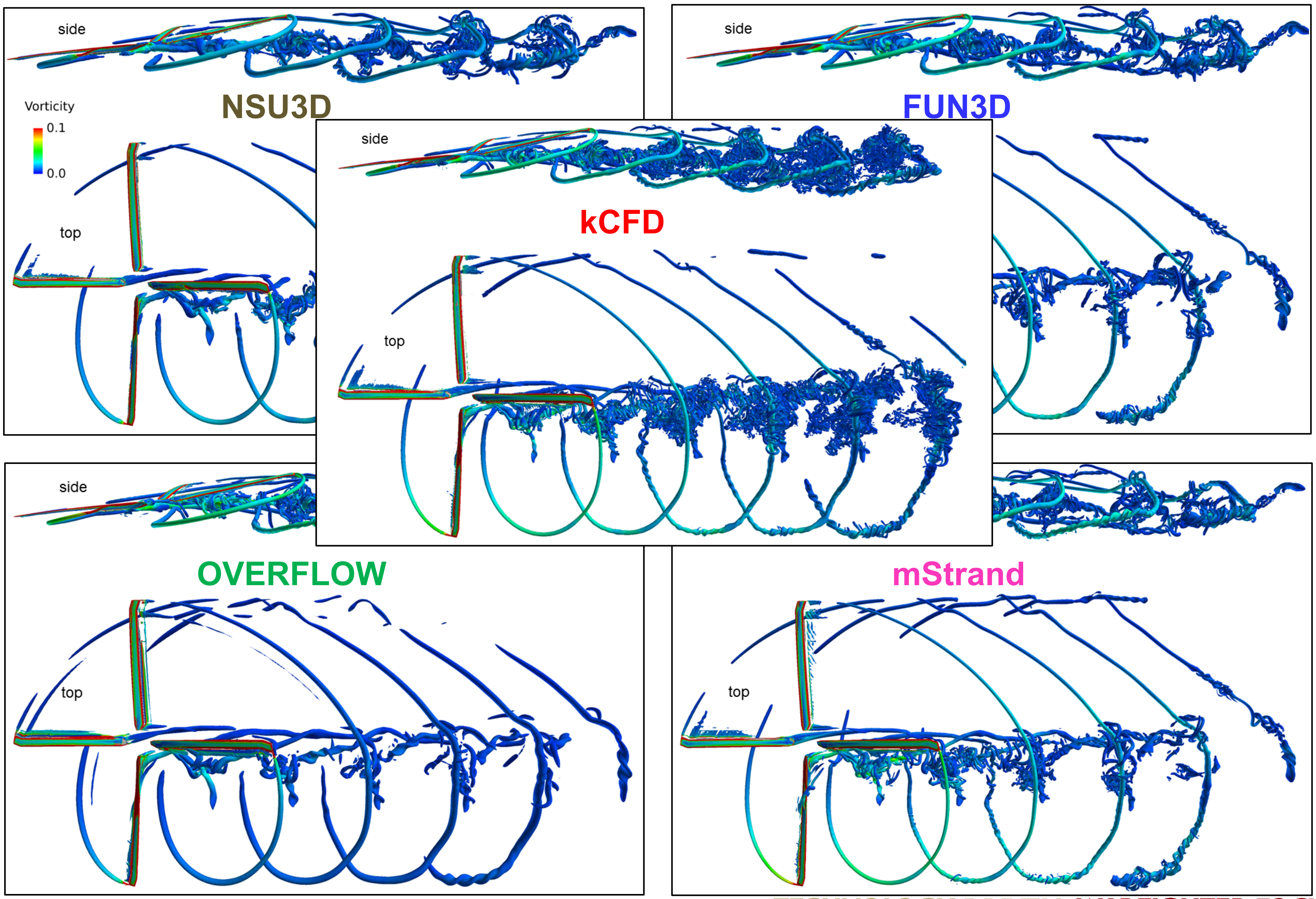






Nearly identical results

UH-60A Wake


side
Vorticity
0.1
0.0
top
NSU3D
side
FUN3D
side
kCFD
top
side
OVERFLOW
top
mStrand
top

Concluding Remarks

- **Several key new features in Helios version 7**
  - New Strand mesh generation and solver
  - Redesigned GUI with support for bodies/frames/motion
  - Support for kCFD & FUN3D near-body solvers (in addition to NSU3D and OVERFLOW supported in past versions)
  - Support for tight coupling maneuver
- **Multi-solver support in Helios**
  - Provides practicing engineer the ability to perform multi-code comparisons for real problems
  - Common force reporting and visualization makes code comparisons straightforward
  - Useful to assess new strand solver, and new solvers in general
  - Ability to rapidly bring in new capabilities e.g. transition modeling
- **We welcome collaborative efforts!**
  - Helios has interfaces to key NASA codes – OVERFLOW, FUN3D, CAMRADII
  - It now has support for complex multi-body dynamics
  - Shared Army/NASA goals for higher order in space/time, better turbulence modeling, automated mesh generation, HPC accelerators (Intel KNL), …

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Helios Development Team

Dr. Roger Strawn
Dr. Anubhav Datta

Quality Assurance Team

Dr. Joe Laiosa
Dr. Jennifer Abras

Integration Team

Mr. Stephen Adamec
Mr. Brian Pittman

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